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# Carrier accumulation due to insertion of nanoscale As clusters into n- and p-type GaAs

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**Abstract.** Accumulation of electrons and holes has been revealed by capacitance-voltage technique in As-cluster containing GaAs layers sandwiched between n-type or p-type GaAs buffers. As a result of the majority carrier accumulation, a large depletion region forms in adjacent buffers. Simulation of the capacitance-voltage characteristics based on numerical solution of the Poisson equation showed the concentration of accumulated charge carriers to be as high as $\simeq 1 \times 10^{12}$ cm$^{-2}$ which is comparable with concentration of As clusters determined from transmission electron microscopy study.

## Introduction

Gallium arsenide containing nanoscale arsenic clusters (so called LT-GaAs) has attracted much attention in the past few years due to its unique properties, such as a very high electrical resistivity and extremely short (femtoseconds) carrier lifetime [1–4]. While this material has found several device applications, the nature of its electronic properties is still under discussion. Our previous investigations showed that the As-cluster containing material can accumulate electrons from adjacent n-GaAs layers [5, 6]. In this paper we report on capacitance-voltage (CV) study of Schottky barrier structures where LT-GaAs layer is sandwiched between p- or n-type GaAs buffers. We elucidate fundamental difference in the electron and hole accumulation in LT-GaAs layers.

## 1. Experimental details

N(P)-type structures consisted of three layers 0.5 $\mu$m–thick n(p)–GaAs/0.1 $\mu$m–thick LT-GaAs/0.5 $\mu$m–thick n(p)–GaAs and were grown by MBE on n$^+$(p$^+$)–substrate with (100) orientation, where n(p)-type buffers were grown at 580°C and doped with Si(Be) up to concentration of $2 \times 10^{16}$ cm$^{-3}$. The LT-GaAs layer was grown at 200°C and doped with the same concentration of shallow impurities. These growth conditions result in a high arsenic excess ($\simeq$1.5 at.%) in the LT-GaAs layer. Arsenic clusters were produced in LT-GaAs matrix during the growth of the upper buffer layer. The P-type structure was capped by a 38 nm–thick GaAs/AlAs (1 nm/1 nm) short-period superlattice (SPSL). Alloy of AuGe (AuZn) was evaporated and alloyed on the n$^+$(p$^+$)–substrate to produce ohmic contact. The Au circular Schottky contacts had a diameter of 0.4 mm and 0.5 mm for the N- and P-type structures, respectively.

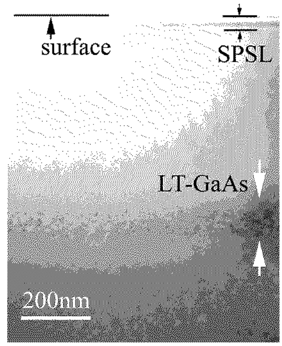


**Fig. 1.** Bright-field cross-sectional TEM image ($g = 220$) of P-type structure.

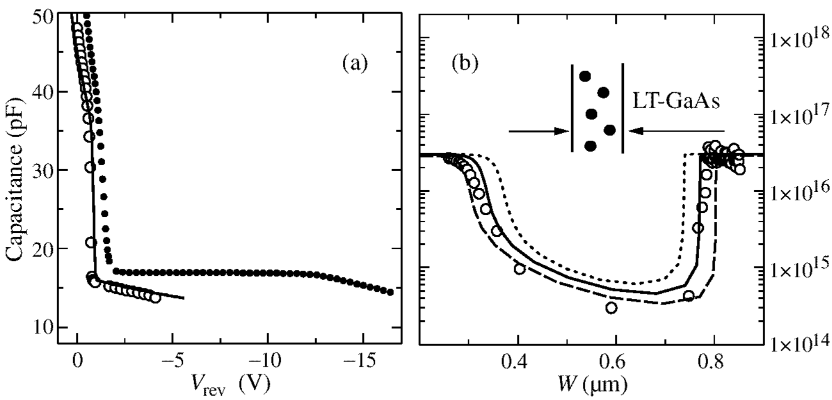


**Fig. 2.** CV characteristics (a) and apparent concentration profiles $N_{CV}(W)$ (b) of N-type structure: experimental data ($T = 290$ K (∘) and $T = 94$ K (•), measurement frequency 10 kHz) and model simulations with different concentration of the charge carriers in LT-GaAs layer $N_Q^{LT}$: $0.8 \times 10^{12}\,\text{cm}^{-2}$ (dotted), $1.0 \times 10^{12}\,\text{cm}^{-2}$ (full), $1.2 \times 10^{12}\,\text{cm}^{-2}$ (dashed). The insert in Fig. 2(b) shows the position of LT-GaAs layer.

## 2. Results and discussion

Figure 1 shows a cross-sectional transmission electron-microscope (TEM) image of the P-type structure. It can be seen that the LT-GaAs layer containing arsenic clusters is as thick as $\simeq 0.1\ \mu$m and is sandwiched in between two cluster-free p-layers. The sheet As cluster density ($N_{cl}$) is $\approx 6 \times 10^{11}\,\text{cm}^{-2}$, and their average diameter is 5–7 nm. TEM image of N-type structure reveals As clusters with $N_{cl} \approx 4 \times 10^{11}\,\text{cm}^{-2}$ and a diameter of 6–8 nm [6]. It should be noted that no extended defects have been observed by TEM in the both P- and N-type structures.

CV-characteristics of N- and P-type structures are shown in Figs. 2(a) and 3(a), respectively. Apparent concentration profiles (Figs. 2(b) and 3(b)) were calculated from the CV characteristics using the depletion region approximation:

$$N_{CV}(W) = \frac{C^3}{q\varepsilon\varepsilon_0(dC/dV)},\ W = A\frac{\varepsilon\ \varepsilon_0}{C} \tag{1}$$

where $q$ is the charge of electron, $\varepsilon_0$ is the dielectric constant of the vacuum, $\varepsilon$ is the

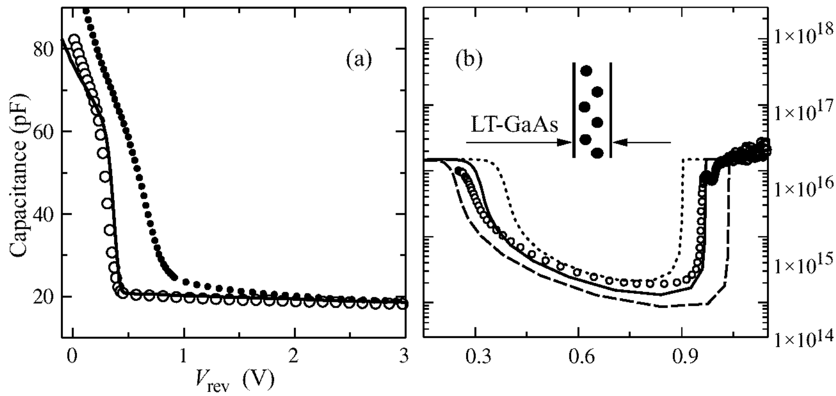


**Fig. 3.** CV characteristics (a) and apparent concentration profiles $N_{\mathrm{CV}}(W)$ (b) of P-type structure: experimental data ($T = 290$ K (∘) and $T = 77$ K (•), measurement frequency 10 kHz) and model simulations with different concentration of the charge carriers in LT-GaAs layer $N_Q^{\mathrm{LT}}$: $6.0 \times 10^{11}\,\mathrm{cm}^{-2}$ (dotted), $8.0 \times 10^{11}\,\mathrm{cm}^{-2}$ (full), $1.0 \times 10^{12}\,\mathrm{cm}^{-2}$ (dashed). The insert in Fig. 3(b) shows the position of LT-GaAs layer.

dielectric constant of the semiconductor, $W$ is the depth from the surface of the structure, and $A$ is the area of the Schottky barrier contact.

One can see from Figs. 2(a) and 3(a) that CV characteristics of both structures are similar at low temperature. The specific feature of the CV characteristics is an abrupt drop of the capacitance when depletion region from the surface of the structure reaches a wide built-in depletion region induced by the cluster containing LT-GaAs layer. Using numerical solution of the one-dimensional Poisson equation [7], we have simulated the CV and $N_{\mathrm{CV}}(W)$ characteristics of both N- and P-type structures at low temperatures (Figs. 2 and 3). It was found that the depletion around LT-GaAs layer arises from the accumulation of the majority carriers. The best fit of the experimental curves was obtained with a concentration of accumulated electrons of $N_Q^{\mathrm{LT}} \approx 1 \times 10^{12}\,\mathrm{cm}^{-2}$ in N-type structure and a concentration of accumulated holes of $N_Q^{\mathrm{LT}} \approx 8 \times 10^{11}\,\mathrm{cm}^{-2}$ in P-type structure. The concentrations of the accumulated carriers in the LT-GaAs layers are comparable with the concentrations of the As clusters obtained from TEM study.

With elevating temperature a pronounced difference appears between CV characteristics of the N- and P-type structures. In the case of N-type structure (Fig. 2(a)) after an abrupt drop of capacitance at 1.0 V one can see a wide plateau in the range from 2 V to 12 V. The plateau on the CV characteristic (Fig. 2(a)) relates to electron emission from the LT-GaAs layer [5, 6]. In contrast, in the case of the P-type structure (Fig. 3(a)) no hole emission can be observed at temperatures $\leq$300 K. From the analysis of the frequency and temperature dependencies of the CV characteristics the electron emission rate is found to be higher than the hole emission rate by at least several orders.

## 3. Conclusions

We studied CV characteristics of N- and P-type sandwich structures where As-cluster containing LT-GaAs layer was inserted between n-type or p-type GaAs buffers. Majority carrier accumulation was revealed in the LT-layers. Accumulated carrier concentration was found to be comparable with arsenic cluster density determined by TEM. A strong

difference between electron and hole emission rates from cluster-containing LT-GaAs layers was observed.

*Acknowledgements*

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